Simulating the Effects of Multiple Stressors on At-Risk Populations

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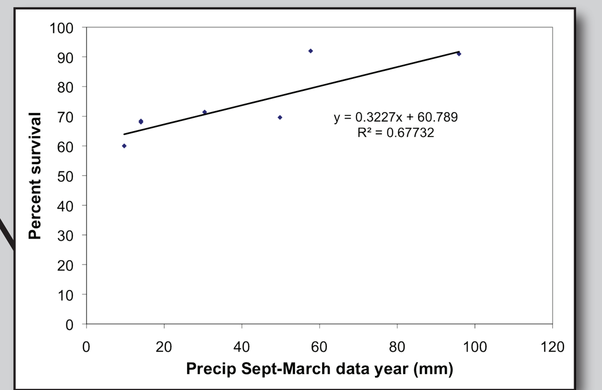
Introduction

Species at risk of extinction often face multiple interacting threats. Successfully and efficiently managing at-risk populations requires an understanding of how these threats interact, and which will have the greatest impact on population persistence. To aid in the management of species facing multiple threats, we developed a flexible, spatially-explicit population model designed to simulate a wide range of species in complex and changing landscapes.

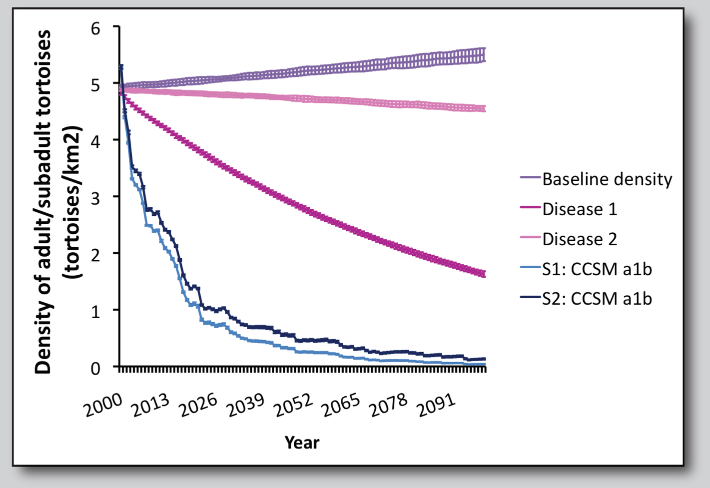
Desert Tortoise, Disease, and Climate Change, Fort Irwin, CA

We modeled the combined effects of disease and climate change on the desert tortoise at Fort Irwin in the Mojave Desert. Data from multiiple studies demonstrate a relationship between adult mortality in diseased populations and winter precipitation (bottom left). HexSim simulations resulted in forecasts of continued steady and dramatic declines in the population as a result of upper respiratory tract disease. These simulations indicate that an increase in forage availability has the potential to reduce population declines; however, climate-change projections do not exhibit the increases in precipitation necessary to produce such increases in forage availability.

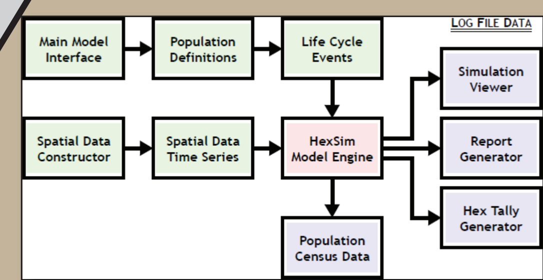
Empirical relationship between Sept-March rainfall and survival rates in populations with upper-respiratory tract disease in the Western Mojave (below). Data are from multiple pulbished papers.



Simulated effects of climate and disease on desert tortoise density in the Western Mojave (below). We modeled tortoise populations under five scenarios of disease and climate change: with no disease (Baseline density), with a lower estimate of disease-induced adult mortality (Disease 1), with a higher estimate of disease-induced adult mortality (Disease 2), and with the combined effects of disease and projected changes in precipitation from the CCSM general circulation model under a mid-range greenhouse-gas emissions scenario (S1 and S2: CCSM a1b).



The HexSim Population Model

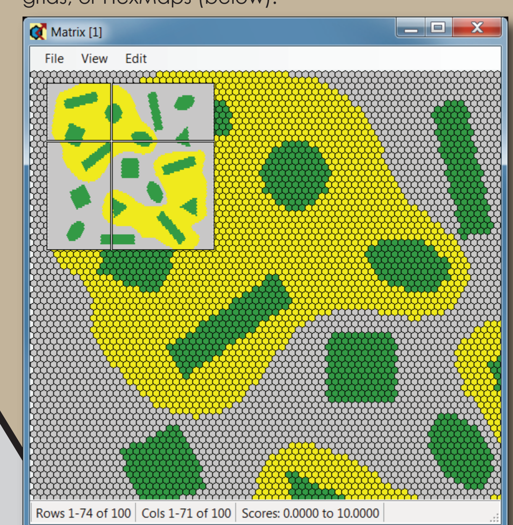


HexSim is a spatially-explicit, individual-based computer model designed for simulating terrestrial wildlife population dynamics and interactions. HexSim is very general, with landscapes, life histories, disturbance regimes, and most other details being supplied by the user at run-time. The model uses spatial data to capture landscape structure, habitat quality, stressor distribution, and other types of information. HexSim's design makes it ideal for exploring the cumulative impacts on wildlife populations resulting from multiple interacting stressors.

The HexSim environment (left) includes a graphical user interface, utilities for importing spatial data, the underlying HexSim model engine, and utilities for visualizing simulations and extracting population data.

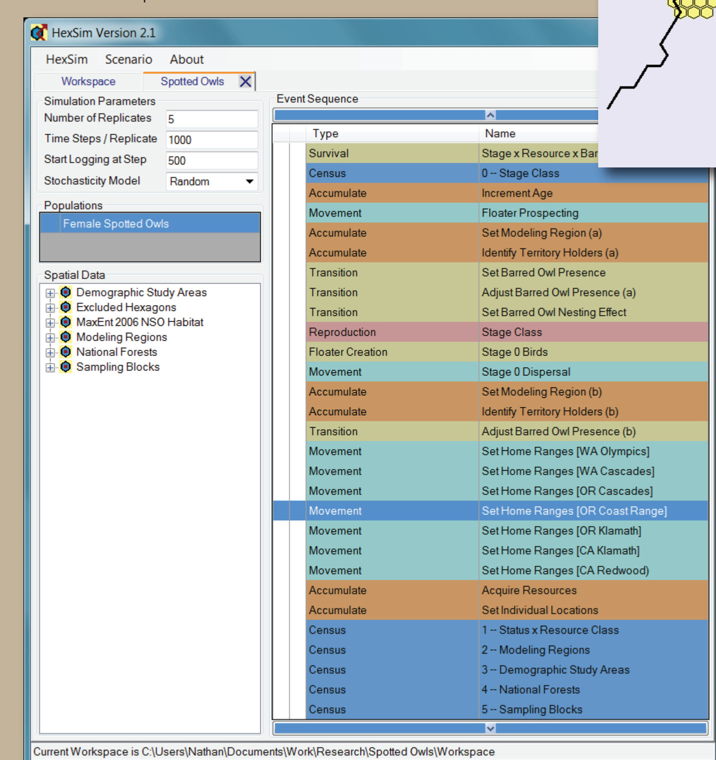
Each population in HexSim is composed of individuals, and individuals have traits that can change probabilistically, or based on age, resource availability, disturbance, competition, and other factors. HexSim also includes optional genetics and heritable traits. The use of traits allows individuals to have unique properties that change in time and space. Traits also allow populations to be segregated into classes, such as males and females, fitness categories, disease categories, etc. Combinations of trait values can be used to stratify events such as survival, reproduction, or movement.

Spatial data in HexSim are represented by hexagon grids, or HexMaps (below).

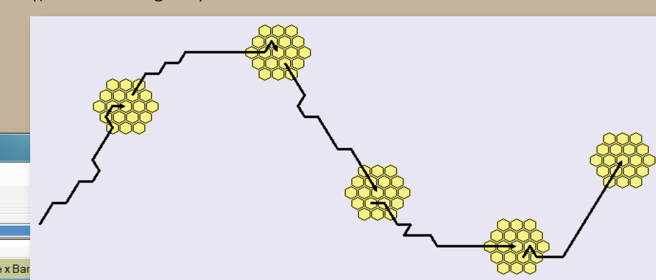


HexSim simulations are built around a user-defined life cycle. The life cycle consists of a sequence of life-history events, including survival, reproduction, movement, resource acquisition, species interactions, and many others.

HexSim's graphical user interface (below) allows the user to assemble events into a life cycle and manage associated spatial data files.



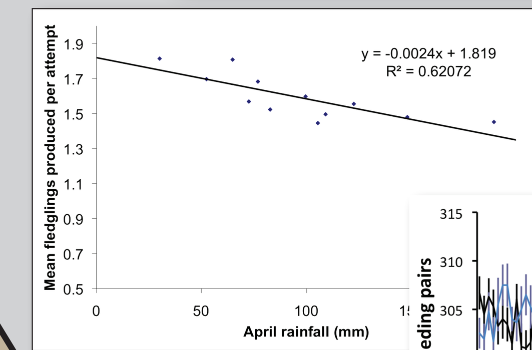
An example (below) of linked dispersal (black lines) and exploration (yellow hexagons) events for an individual in the HexSim model.



Red-cockaded Woodpecker, Land-use, and Climate Change Fort Benning, GA

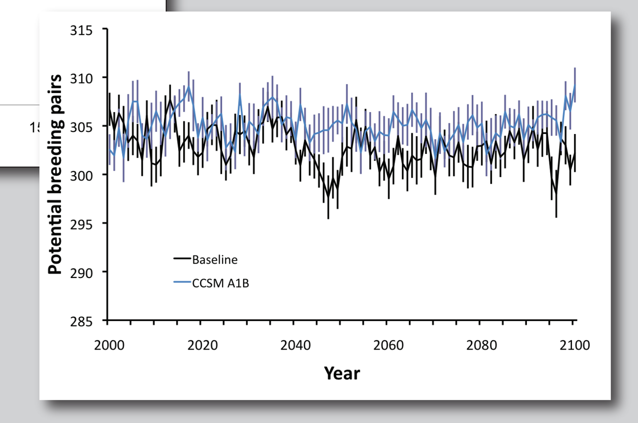
Red-cockaded woodpeckers inhabit mature stands of longleaf and loblolly pine on Fort Benning. Habitat loss due to development and declining loblolly pine is the greatest threat to the woodpecker. However, woodpecker productivity is affected by rainfall and may therefore be impacted by future climate change.

We simulated the potential impacts of forest management and projected rainfall on woodpecker populations at Fort Benning. Our results indicate that future development at Fort Benning will likely have a greater effect on the woodpecker population than will climate change. However, in the absence of continued longleaf pine restoration, the current age structure of the forests and current patterns of tree mortality at Fort Benning will lead to significant declines in the woodpecker population over the latter half of the century.

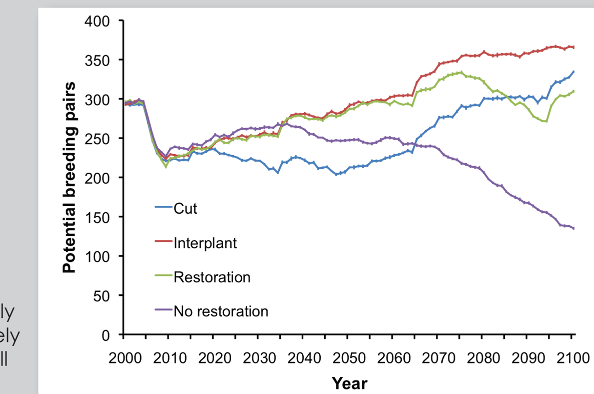


Woodpecker productivity decreases with increasing April rainfall (left).

Projected climate-driven changes in precipitation are unlikely to have a significant effect on woodpecker population trends. Simulated numbers of woodpecker breeding pairs under a baseline scenario of current precipitation and forecast precipitation from the CC2M global climate model under the A1B emissions scenario (below).



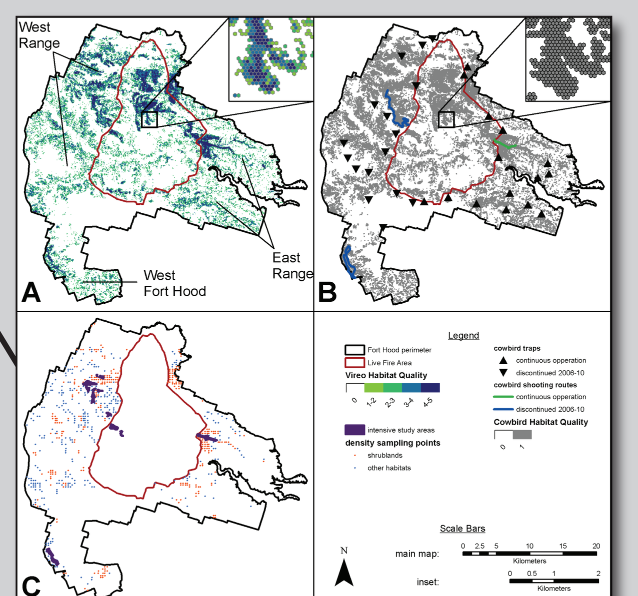
Without continued restoration of longleaf pine stands, red-cockaded woodpecker populations are projected to decline beginning in 2035 (right). Management scenarios that involve restoration (replanting scenescing loblolly pine stands with longleaf), cutting (removing loblolly stands and replacing them with longleaf), and interplanting (selectively removing loblolly trees in mixed stands and replanting with longleaf) all resulted in increases in the woodpecker population over 100 years.



Black-capped Vireo and Cowbirds, Fort Hood, TX

Cattle on Fort Hood (left).
A cowbird trap placed in cowbird foraging habitat (below).

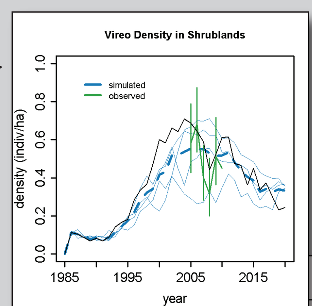
Brood parasitism by brown-headed cowbirds poses the greatest threat to the Fort Hood black-capped vireo population. Cowbirds are associated with livestock and residential areas on and surrounding Fort Hood. Trapping and shooting of cowbirds have allowed vireo populations to recover.

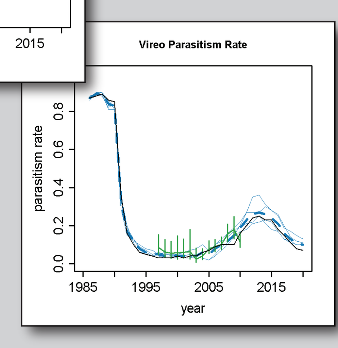


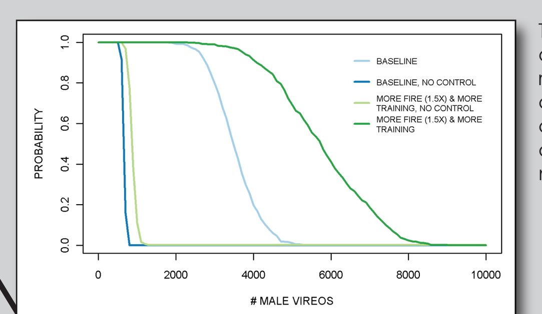
We input spatial data layers into HexSim for vireo and cowbird habitat suitabilty as well as cowbird trapping sites and shooting routes (left, panels A & B).

We used survival and productivity estimates from intensive monitoring sites and density estimates from base-wide vireo surveys (left, panel C) to parameterize a vireo-cowbird population model incorporating cowbird management, parasitism, and environmental stochasticity.

The HexSim model recreates observed increases in vireo density with trapping conducted throughout Fort Hood from 1992-2005 as well as the decrease in vireo numbers and increase in parasitism that occured with the cessation of trapping on the west half of Fort Hood from 2006-2010 (right).







The probabilty of maintaining at least 1000 breeding pairs of vireos on Fort Hood is high under a baseline scenario reflecting current disturbance rates and a scenario for climate-induced increases (1.5X) in area burned when cowbird trapping and shooting is continued. In the absence of cowbird management, the probability of maintaining 1000 vireos falls to zero under both scenarios.

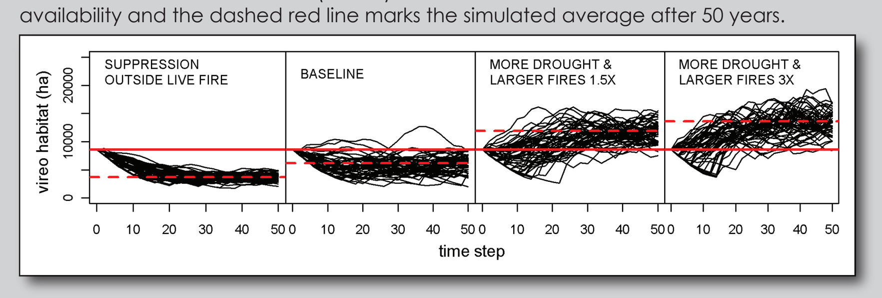
Black-capped Vireo, Military Training, Fire Suppression, and Climate Change, Fort Hood, TX

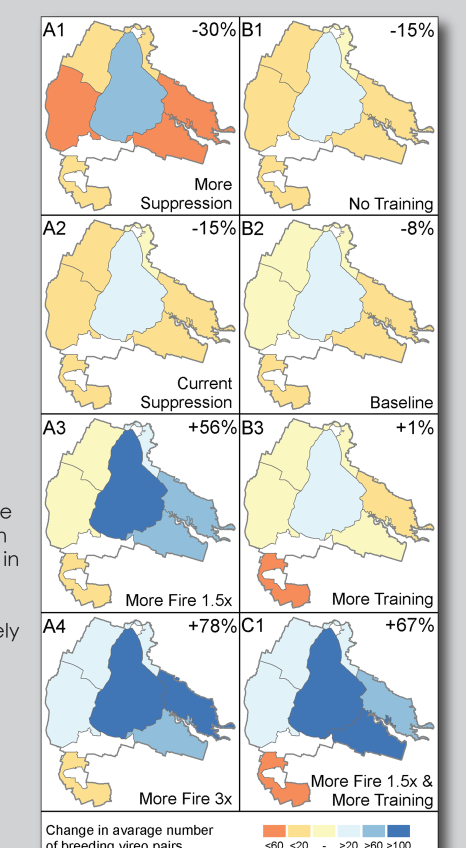
Vireos breed in deciduous shrubland habitats historically maintained by fire. These shrublands have a patchy configuration and are dominated by oak species. In the absence of fire, shrublands become oak-juniper woodlands and are no longer suitable for vireos.

Military training at Fort Hood involves manuevering of large vehicles off-road. Disturbance from training maintains a patchy configuration in vegetation prefered by vireos and slows the transition to woodlands.

We simulated future vegetation growth and disturbance from fire and miltary training to explore the impacts of fire suppression and climate-induced increases in area burned on vireo habitat availability. We then input maps of projected vireo habitat into the HexSim vireo-cowbird population model to estimate the potential impacts on vireo populations.

Altered fire regimes will likely have a greater impact on future vireo habitat availability than will military training. Fire suppression reduces habitat, and climate-induced increases in fire create habitat (below). The solid red line marks current vireo habitat availability and the dashed red line marks the simulated average after 50 years.





Scenarios for fire suppression (right, A1 and A2) lead to declining vireo abundance, particularly in regions outside of the central Live Fire Area of Fort Hood. Scenarios for climate-induced increases in fire (A3 and A4) lead to increasing vireo abundance, particularly in the eastern ranges.

Expansion and contraction of miltitary training activites moderately impact vireo abundance (B1-3). The cumulative effect of increased training and climate-induced increases in fire extent is increased vireo abundance, particularly in the southestern region of Fort Hood (C1).

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